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THE UPPER ATMOSPHERE OF MARS

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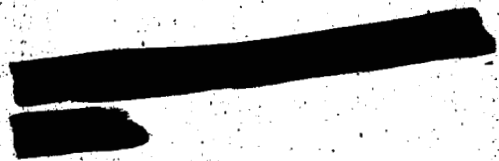
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ABSTRACT

The thermal structure of the upper atmosphere of Mars has been theoretically investigated. It is found that the exospheric temperature, for a pure CO_2 model atmosphere, lies between 400 - 700 °K. The origin of the Martian atmosphere is discussed in the light of these results.



THE UPPER ATMOSPHERE OF MARS

The recent spectroscopic measurements^{(1) (2)} and the results of the Mariner IV occultation experiment⁽³⁾ indicate that the atmosphere of Mars may be mainly composed of CO_2 with a total atmospheric pressure at the surface of 5 - 10 mb. Using this model we have calculated the thermal structure of the upper atmosphere. The results indicate that the exospheric temperature of Mars may be $550 \pm 150^\circ\text{K}$ (Figure 1). The temperature profile is consistent with the temperature deduced from the Mariner IV occultation experiment.

The method of computation and the basic assumptions made for these calculations are as follows: It is assumed that the average temperature of the planet at the surface is 200°K , the lower atmosphere up to 80 km is in radiative equilibrium, and the temperature profile for this region has been calculated from the method described by Prabhakara and Hogan⁽⁴⁾. At this level the dissociation of CO_2 by the solar ultraviolet becomes effective and we assume that above 80 km the dissociation products of CO_2 , viz., CO and O, are in diffusive equilibrium.

The temperature structure in the thermosphere and

exosphere is calculated by the method described in detail by Chamberlain⁽⁵⁾, McElroy, L'Ecuyer and Chamberlain⁽⁶⁾, and Rasool, Gross and McGovern⁽⁷⁾. The input of energy in this region is mainly in the far ultraviolet through the ionization of atomic oxygen, while the emission is by CO₂ and CO. It has already been shown that the presence of CO in the upper atmosphere is extremely effective in reducing the exospheric temperature mainly because the emission is proportional to T^2 ⁽⁶⁾. It is for this reason that the Martian exosphere is at a temperature as low as $\sim 550^\circ\text{K}$ compared to the earth where $T_{\text{ex}} \sim 1500^\circ\text{K}$. The large uncertainty of $\pm 150^\circ\text{K}$ in the value of T_{ex} for Mars as shown in Figure 1 results from the uncertainties in the value of the solar flux in the extreme ultraviolet, the exact fraction of solar energy that goes into heating, and also the level at which CO radiation becomes effective.

Our results, as shown in Figure 1, differ considerably from the temperature profile for Mars recently published by Johnson⁽⁸⁾ in which the upper atmosphere is isothermal at 85°K . Johnson's value for the temperature is derived from the observation of Mariner IV's occultation experiment that the electron density scale height above 125 km on Mars is 25 km. The neutral gas density scale height will then be

12.5 km. If the principal ion is O^+ , then for an isothermal atmosphere the temperature should be $85^\circ K$. However, it must be pointed out that if there is a positive temperature gradient, then the actual scale height in the atmosphere can be much larger than the isothermal scale height. For an atmosphere in hydrostatic equilibrium, the two scale heights, H and H' (actual and isothermal), are related by the following expression:

$$H = \frac{H'}{1 - \frac{H'}{T} \frac{dT}{dz}} \quad (1)$$

Johnson assumes $\frac{dT}{dz} = 0$ and therefore infers that $H = H' = 25$ km. But, as seen from Equation (1), depending on the temperature gradient and the actual temperature of that region, a number of solutions for H are possible. If, for example, we assume that, in the atmospheric region explored by Mariner IV's occultation experiment, ($55^\circ S$, winter), $\left(\frac{dT}{dz}\right)_{125 \text{ km}} = 2^\circ K/km$ (Figure 1) and $T_{125 \text{ km}} = 150^\circ K$, then for $H' = 25$ km, $H = 37.5$ km. This scale height will be consistent with an atomic oxygen atmosphere at $T \sim 150^\circ K$.

The calculated temperature at 125 km altitude (Figure 1) is slightly higher than $150^\circ K$, mainly because our model is an average for the whole planet, while the occultation experiment results concern the Martian atmosphere at $55^\circ S$,

winter hemisphere, in the local afternoon.

It therefore seems clear that Johnson's model is based on only one of several ways in which the electron density scale height measurements can be interpreted. It has the further disadvantage of putting stringent requirements on the energetics of the thermosphere. An isothermal thermosphere implies that at each height, the amount of absorption of ultraviolet radiation exactly equals the emission by CO_2 and CO at that height. It is difficult to see how this condition will be met at all times and at all points on the planet.

Origin of the CO_2 in the Atmosphere of Mars

Our result that the exospheric temperature of Mars may be in the neighborhood of 550°K has some interesting implications regarding the origin of the observed CO_2 on Mars.

At $T_{\text{ex}} = 550^\circ\text{K}$, both H_2 and He will be lost rapidly, but O will not escape. The present atmosphere of Mars may therefore be a remnant of a heavier primitive atmosphere which once had a composition similar to that observed today on Jupiter, viz., large quantities of H_2 and He with small amounts of CH_4 , NH_3 , Ne, and probably H_2O . Once H_2 and He have escaped, the residual atmosphere will be mainly composed

of CO_2 with relatively small but substantial amounts of Ne and N_2 ⁽⁷⁾. If this is the process by which the atmosphere of Mars has evolved, then the exospheric temperature on Mars should be greater than the escape temperature for He, but less than the escape temperature for O, i.e., $1100 > T_{\text{ex}} > 250^\circ \text{K}$. Also, if the total amount of CO_2 in the Martian atmosphere is 5 mb, then from the cosmic abundance table it follows that there must also be at least 2 mb of Ne and 1 mb of N_2 in the atmosphere⁽⁹⁾. Both these gases are difficult to observe from the earth, and their identification on Mars must therefore await in situ exploration of the planet in the next few years.

Johnson has proposed the alternative hypothesis that the present atmosphere of Mars is a result of outgassing from the interior. This will imply that the atmospheric pressure on Mars was never greater than the present value of ~ 10 mb and that there must be large quantities of frozen water present under the surface of Mars⁽⁸⁾.

Only the future flybys and landers on Mars will be able to test these conjectures by measuring the exospheric temperature, searching for rare gases by mass spectrometer, and examining the surface properties of the planet. These questions, regarding the origin and evolution of the Martian

atmosphere, are not only of profound scientific interest, but are also of the greatest general and philosophical importance because they relate to the primitive physical environment of the planets and the circumstances under which life may have developed on the earth and on other bodies in the solar system.

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- (9) For this composition the exospheric temperature of Mars is reduced by approximately 10% of that shown in Figure 1, mainly because of the higher conductivity of neon.
- (10) One of us (W.E. McGovern) was supported by NASA grant N.S.G. 499.

FIGURE CAPTION

Figure 1: Vertical distribution of temperature in the atmosphere of Mars. The range of uncertainty in the temperature of the upper atmosphere, $\pm 150^\circ\text{K}$, is shown as the hatched area. An atmosphere of pure CO_2 with a surface pressure of 8 mb was assumed.

